NASA
SPACE VEHICLE
DESIGN CRITERIA
(STRUCTURES)

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DESIGN-DEVELOPMENT TESTING

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform criteria for the design of space vehicles. Accordingly, criteria are being developed in the following areas of technology:

Environment
Structures
Guidance and Control
Chemical Propulsion

Individual components of this work will be issued as separate monographs as soon as they are completed. A list of all previously issued monographs in this series can be found at the end of this document.

These monographs are to be regarded as guides to design and not as NASA requirements, except as may be specified in formal project specifications. It is expected, however, that the criteria sections of these documents, revised as experience may indicate to be desirable, eventually will become uniform design requirements for NASA space vehicles.

This monograph was prepared under the cognizance of the Langley Research Center. The Task Manager was W. C. Thornton. The authors were T. P. Brooks and L. D. Mutchler of McDonnell Douglas Corporation. Other individuals assisted in developing the material and reviewing the drafts. In particular, the significant contributions made by H. P. Adam and N. K. Jamison of McDonnell Douglas Corporation; E. F. Baird and R. Hilderman of Grumman Aircraft Engineering Corporation; T. N. Bartron of NASA Langley Research Center; M. D. Brinson of Ling-Temco-Vought Corporation; E. G. Davies of Lockheed Missiles & Space Company; M. Dublin of General Dynamics Corporation; J. S. Gilbert of Chrysler Corporation; O. L. Gillette of Hughes Aircraft Company; F. P. Klein of Electronic Specialty Company; H. W. Klopfenstein and H. J. Runstad of The Boeing Company; C. E. Lifer of NASA George C. Marshall Space Flight Center; D. R. Reese of Wyle Laboratories; and L. St. Leger of NASA Manned Spacecraft Center are hereby acknowledged.

NASA plans to update this monograph when need is established. Comments and recommended changes in the technical content are invited and should be forwarded to the attention of the Design Criteria Office, Langley Research Center, Hampton, Virginia 23365.

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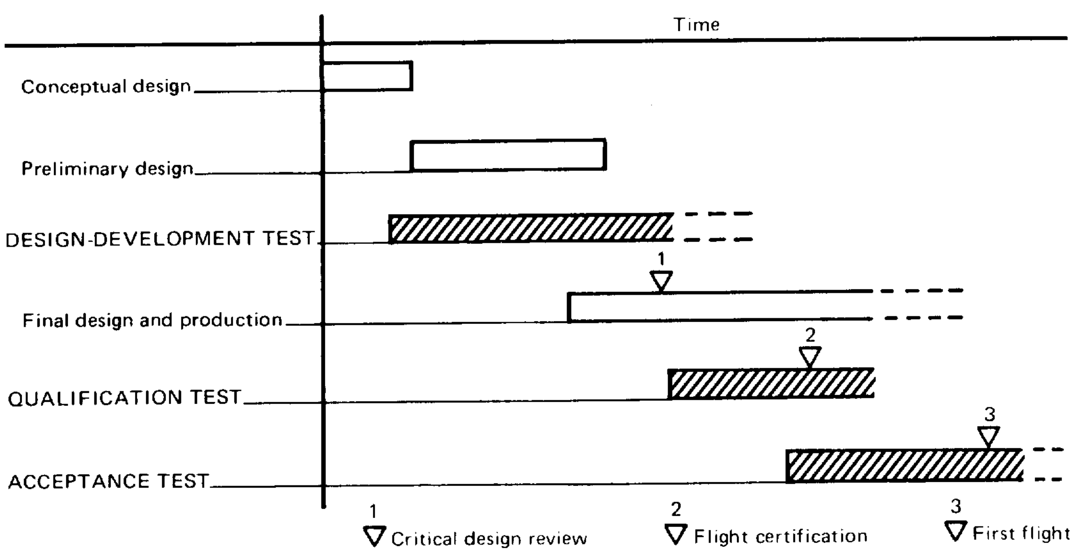
DESIGN-DEVELOPMENT TESTING

1. INTRODUCTION

Design-development tests are used by the designer and analyst to confirm the feasibility of a structural design approach, demonstrate the advantage of one design over another, identify failure modes, confirm analytical methods, or generate essential design data. The amount of testing depends largely on the degree of sophistication of the structure and on the quantity of qualified hardware used in the design. Designs utilizing conventional hardware will obviously require less testing than designs which advance the state of the art. These tests are not normally specified by contract and are not as closely controlled by the customer as are qualification and acceptance tests.

The design-development tests are the first of three kinds of tests conducted in a typical hardware development program, as shown in figure 1. Qualification tests are conducted to demonstrate that structural design requirements have been achieved. Acceptance tests verify that the materials, manufacturing processes, and workmanship used to produce the flight hardware have met the design specifications. The specific



NOTE: Overlap of events represents a practical rather than ideal situation on typical programs

Figure 1. – Typical test-program phasing.

characteristics of these different tests are shown in table I. With the satisfactory completion of these tests, the flight hardware is considered to be structurally and operationally adequate for flight.

Improper preparation of the test plan or improper selection and definition of the test condition, specimen, support structure, data, or instrumentation can result in invalid data, misinterpretation of data, and incorrect conclusions.

For example, a modal vibration test was performed on a shell structure to confirm and modify theoretical predictions of mode shapes, natural frequencies, and damping. However, because of minimal instrumentation and support structure which was not representative of flight structure, the test did not uncover nonpredicted low-frequency modes associated with a large concentrated mass; these modes later proved to be more important than the predicted high-frequency modes because they produced much higher stress levels than did the high-frequency modes. The test had to be repeated with proper support structure, more comprehensive instrumentation, and more specific data requirements.

In another case, the first production article for a pressurized cylindrical compartment had to be scrapped because the strength of resistance seam welds was not adequate. The seam weld nugget attaching the skin to the rings was predominantly in the ring and not at the skin/ring interface. This occurred because the design-development tests were conducted on flat specimens. Consequently, the radii of the copper wheels used as electrodes were not properly determined for use in welding the curved production article.

The need for a design-development test and the type of test to be conducted are determined by: (1) a lack of confidence in analytical predictions of structural

TABLE I. - STRUCTURAL TESTS

Tests	Load levels	Purpose	Type of hardware used
Design-development	Variable, often to destruction.	To determine ultimate strength and design feasibility.	Decided by engineering.
Qualification	To design ultimate load (not necessarily to failure).	To verify structural adequacy.	Flight quality.
Acceptance	Usually not exceeding flight-limit loads (except for pressure-proof tests).	To ensure hardware meets specifications.	Flight.

capability, (2) the use of new fabrication techniques, and/or (3) a lack of previous industry and in-house experience.

This monograph is concerned with the testing of any element or component whose principal function is structural. Criteria are presented and recommendations made for planning tests and establishing test requirements. The mechanics of performing the tests are not treated in this document.

Types of design-development tests and the gross information which may be derived from each type are given in table II. Listed types of tests are defined in the Appendix.

In a well-executed design-development test program, a comprehensive test plan that grossly describes the total test program is prepared as early as possible. In addition, individual test plans that define all details of each test are prepared later. These plans include the number and types of tests, test objectives, number and types of specimens, and the types and amount of data required. All engineering disciplines must achieve early agreement on test data requirements, maintain effective communication, and coordinate activities from formulation of the structural concept through design-development testing.

Other closely related monographs are planned for treatment of qualification testing, acceptance testing, pressure-vessel discontinuities, and combining loads during ascent.

TABLE II. – UTILIZATION OF DESIGN-DEVELOPMENT TESTS

Type of test	Structural capability	Structural characteristics	Active structural performance	Equipment environment and performance
Static	X	X		
Life	X			
Impact/shock	X	X		X
Transmissibility and/or modal vibration		X		X
Acoustic	X	X		X
Environmental vibration	X	X		X
Aeroelastic	X	X		X
Thermal/vacuum		X		X
Functional		X	X	

X indicates test may produce gross information in this area.

2. STATE OF THE ART

Design-development tests are usually performed to obtain necessary design data and to confirm the feasibility of the design concept before the design of the structure is finalized. Ground tests which simulate flight conditions may be limited by available test facilities, but proper specimen design and combinations of loading and environments usually allow test objectives to be fulfilled. There may be occasions when a design-development test meets all the requirements of the qualification test, and the qualification test can therefore be waived.

Published literature on design-development testing is practically nonexistent. The few publications that do exist are addressed primarily to the test engineer and not to the designer or analyst who plans the test. The topic is discussed in company reports with little or no external distribution and occasionally in publications of the American Institute of Aeronautics and Astronautics and the Society for Experimental Stress Analysis. A number of publications (refs. 1 to 9) deal with capabilities of facilities and techniques, but few deal with planning the test program.

Company reports and technical publications usually do not discuss the planning of effective design-development tests. One of the few publications on this subject is reference 10, which deals with the planning of vibration tests. Although emphasis is on fatigue design, reference 11 provides guidelines for planning fatigue tests (referred to as "life tests" in this document); and reference 12 provides guidelines for designing structural models to represent full-scale structure.

Practices for planning tests vary within the aerospace industry, depending on a company's own store of engineering knowledge, manufacturing methods, testing techniques, and facilities.

The principal elements of a design-development test are the test condition, test specimen, support structure, data acquisition, instrumentation, and test report.

2.1 Test Condition

The test condition is often formulated to represent a discrete occurrence or a particular time period during a flight mission if appropriate information about the mission is available. However, the actual representation sometimes reflects a compromise between engineering judgment and limitations of test facilities or other program considerations. The test condition generally specifies the combination of loads and environments. It can, for example, consist of a temperature distribution that is programmed from the time heat is applied until a computed critical load is applied to the heated test specimen. Usually, the structure is tested in one or two of the most severe conditions. The ability of the structure to withstand all other related conditions is predicted by analysis after a satisfactory comparison of test results with analytical results.

Conditions that involve combinations of mechanical, thermal, vibrational, and acoustic loadings are usually simplified to apply only the predominant loadings or to apply each type of loading separately where interaction between loadings is slight or where interactions can be accounted for analytically or by superposition of test results. Design-development tests can be used to demonstrate whether mechanical loads and other environments can be superimposed. Some simple test conditions are first conducted separately and then conducted in combination to determine the validity of analytical superposition.

Frequently, dynamic loading distributions which depend on the support structure and the manner of excitation cannot be represented realistically throughout the entire structure and care must be taken to avoid overtest in local areas.

In tests of auxiliary equipment, the dynamic input spectrum is often shaped to account for impedance mismatch when the equipment is mounted on the test fixture rather than on the actual support structure.

Fractional- or zero-gravity tests are difficult to simulate in ground tests. When analyses are inadequate, various test techniques are used. Among these are counterweights, supports with air bearings to eliminate friction, pendulum-like cable suspension with the spacecraft supported on its side, ballistic trajectories flown with cargo airplanes, and free-fall and underwater tests (ref. 13).

When the actual mission environments cannot be defined by analytical methods or extrapolated from experience into test loads or test environments, a more severe test condition is usually selected to simulate the mission environment qualitatively and provide an indication of the feasibility of the design.

The methods of applying various types of loads and environments and their limitations are presented in table III. The miscellaneous tests listed in the table are not conducted as frequently as the static and dynamic load tests.

2.2 Test Specimen

Test specimens range from standard material coupons to complete structural assemblies. They are usually composed of the lowest level of structural detail or assembly necessary to get meaningful data, and they include only structural elements

TABLE III. – TEST LOADS AND ENVIRONMENTS

Types	Methods of application	Limitations
Static loads		
Inertia and applied forces	Large components usually applied with hydraulic cylinders and distributed load points (whiffletrees).	Loads concentrated at discrete points. Units or areas may be overloaded or completely unloaded.
	Smaller test articles usually applied in a centrifuge. Eliminates need for other loading devices.	Size of the centrifuge – largest available today is with a 25-ft (7.6-m) radius, rated at 1.6×10^6 g lb (7.26×10^5 g kg), or 35 ft (10.7 m) at 4.5×10^5 g lb (20.4×10^4 g kg). Arms can be extended to about a 67-ft (20.4-m) radius, at a lower g force to produce a more uniform force across the test specimen.
Pressure	Applied hydraulically with water or oil as the pressure medium. If a gas is used as the pressure medium, special care is taken for personnel safety.	Possible contamination of the pressure vessel with testing fluid.
		Some state and city safety codes require special precautions with pressure tests, such as testing away from populated areas.
	Often used in conjunction with other applied loads.	
		Remote special facilities are required when cryogenic temperatures must be employed (e.g., LH_2, LO_2).

TABLE III. – TEST LOADS AND ENVIRONMENTS – Continued

Types	Methods of application	Limitations
Dynamic loads		
Vibration	Electrodynamic and electrohydraulic shakers used to apply forces. Large tests may require multiple shakers.	Shaker size electrodynamic 50 000 lbf (222 000 N) and electrohydraulic 200 000 lbf (890 000 N), maximum force rating.
		Size and scope of test limited by the resonant frequency of the test fixture.
Acoustic	Reverberant and progressive wave chambers are available for application of acoustic pressure levels.	Size 200 000 ft^3 (5670 m^3) maximum reverberant chamber size.
		Sound pressure level – 160 to 180 dB (2000 to 20 000 N/m^2).
Shock/ impact	Impact – usually simulated in drop towers with simulated gravity conditions of the flight environment.	Size of machine and ability to apply the shock over large areas.
	Shock – pyrotechnic shock loads are usually simulated on electrodynamic shakers or by firing.	Selectivity of instrumentation having accuracies required for high-g forces.

TABLE III. – TEST LOADS AND ENVIRONMENTS – Concluded

Types	Methods of application	Limitations
Miscellaneous		
Thermal	Thermal heating under ambient pressure conditions is normally applied by infrared radiant-heat lamps.	Maximum heating density 100 Btu/ft^2-sec (1.135 MW/m^2), maximum temperature 3000°F (1922°K)
	Solar heating is usually done with carbon arc lamps or infrared and ultra-violet lamps of the proper spectrum.	Normally performed in a vacuum chamber which limits the size of the test specimens.
	Thermal/vacuum tests are conducted with hot and cold radiation walls using resistance heaters and LN_2 as the mediums.	Maximum temperature range – 320°F (78°K) to 1500°F (1090°K).
Vacuum	Many large sophisticated test chambers are available for vacuum pressures down to 10^{-9} torr (1.33×10^{-7} N/m^2).	Size – approximately 100 ft (30.4 m) in diameter x 120 ft (37 m) high with a volume of 800 000 ft^3 (22 640 m^3).
		Access is difficult during testing.
		Pump-down time – 1 to 2 days, less for smaller chambers.
Functional	Operational test performed under simulated environments which usually include one or more of above tests. Zero gravity is usually simulated by counter forces at discrete points.	As stated above for each load or environment.

or assemblies for which data are required. The ideal test specimen is representative of expected flight hardware; however, for representation of mass characteristics or volume and clearance requirements, dummy components and elements can be used if test objectives are not compromised. Simplification of the specimen is limited by its ability to respond realistically to test loadings. The complexity and size of the test specimen are limited by capabilities of the test facility and the complexity of test loadings.

When adequate scaling techniques are available (e.g., ref. 12), reduced-scale specimens are often used. Test specimens consisting of reduced-scale complete structures may be used in conjunction with full-scale partial structures to acquire data not otherwise available because of size or loading limitations of the test facility or inadequate analytical methods.

Where suitable instrumentation is not available, data can be obtained by testing a series of successively modified test specimens. For example, specimens of different thicknesses may be tested to determine the minimum thickness required to withstand a given acoustical loading. In this way, however, only qualitative results are obtained.

2.3 Support Structure

Well-designed support structure transforms laboratory loading systems into desired test specimen loadings by providing proper boundary conditions for the test specimen. It ensures that mechanical, thermal, vibrational, and acoustic inputs to the specimen are properly introduced and that the response of the specimen is realistic. However, in many design-development tests, no special support structure is used to simulate boundary conditions because the complete design details are not available early enough.

The specimen assembly for a qualification test of the full-scale Saturn S-II/S-IVB interstage and the joint between the interstage and the Saturn S-II forward skirt is shown in figure 2. It illustrates the use of support structure that simulates actual structure (S-IVB dummy aft skirt) and the use of support structure which is identical to actual structure (S-II forward skirt). A method frequently used for transforming loads from laboratory loading systems into the test specimen (loading head assembly) is also shown. All these techniques are used in design-development tests when adequate design information is available.

2.4 Data and Instrumentation

Test data are the physical measurements and observations that qualitatively or quantitatively describe the response of the test specimen to the test loadings and

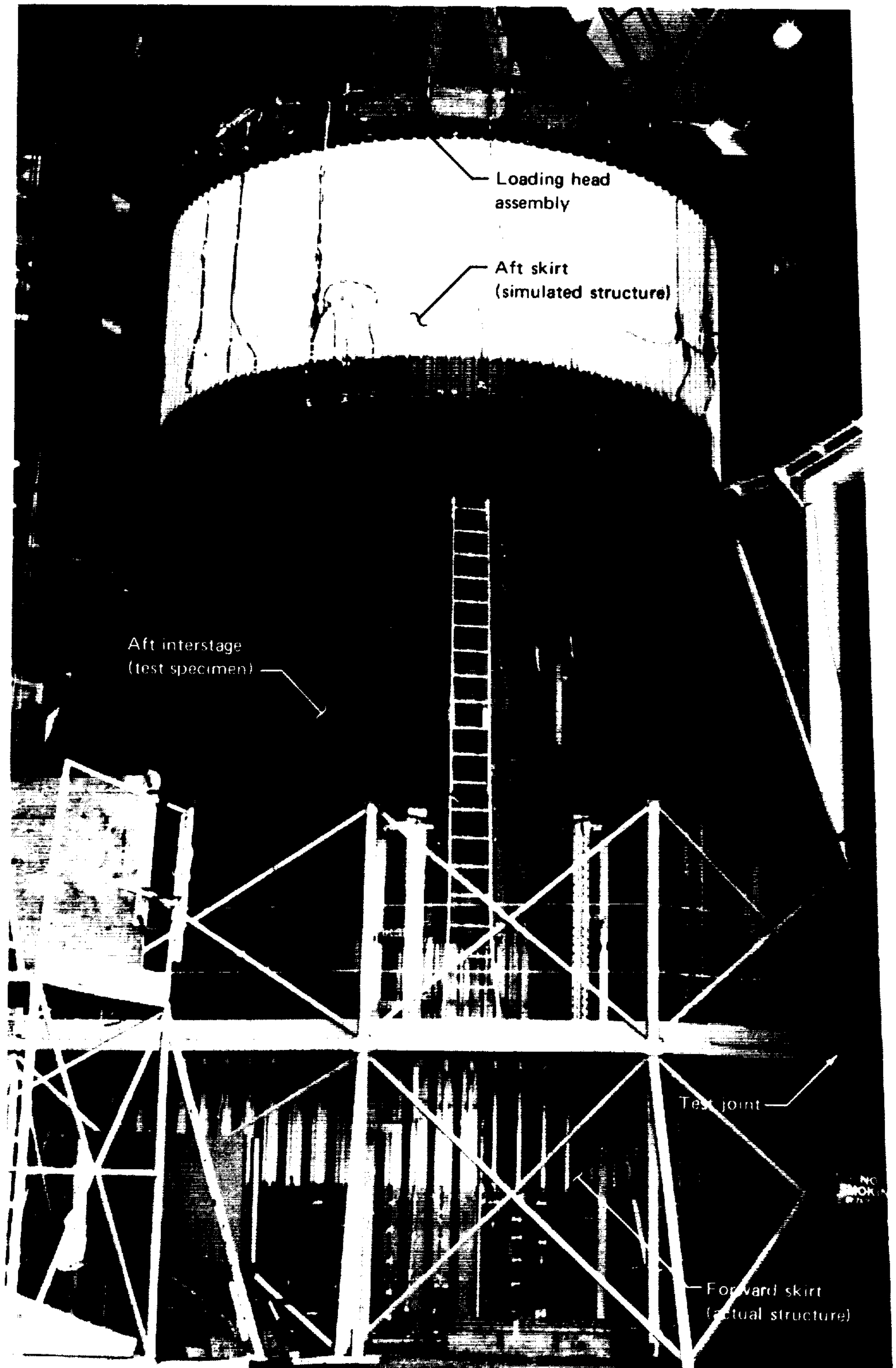


Figure 2. – Test assembly using both simulated and actual support structures.

environments. The use of more sophisticated equipment for data acquisition and data reduction, including on-line analog and digital computers, has greatly increased the amount and quality of data that can be gathered, quickly reduced, and observed in real time. This has had a major impact on the flexibility of data acquisition. In addition, recent advances in strain gages, accelerometers, fatigue strain gages, and photoelastic techniques make data available that previously could not have been gathered.

Measuring sensors used during design-development tests include strain gages, accelerometers, thermocouples, thermistors, deflection gages, pressure gages, and various types of specialized control instruments for defining environmental simulation parameters such as sound-pressure level, vibration frequency and amplitude, heat flux, radiation intensity, and environmental chemistry.

Instrumentation is usually sufficiently accurate for tests when it is used within the manufacturer's recommended operating range. However, when the behavior of the specimen is expected to affect the accuracy of the instrumentation seriously, instruments are recalibrated or relocated, or compensating instrumentation is provided. In addition, supplementary data points are specified and data are conservatively interpreted to compensate partly for insufficient accuracy under extreme operating conditions and to resolve apparent inaccuracies in data.

3. CRITERIA

Structural design-development tests shall be performed to establish the feasibility of the design approach when analytical techniques are inadequate to predict structural performance with confidence. When design-development tests are necessary, a comprehensive test plan and a series of individual test plans which specify the test objectives and the means of achieving them shall be prepared. Specified test objectives shall be achieved, as follows: (1) a specimen, supported by structure that provides realistic boundary conditions, shall be tested with the proper loads and environments; (2) all of the necessary instrumentation shall be specified to obtain the desired design data; and (3) all pertinent data generated in the test shall be documented in a final test report.

3.1 Test Plan

For each space vehicle or each separately contracted segment of a space vehicle, a comprehensive design-development test plan and individual test plans shall be developed in the early stages of the program. These plans shall define and specify, as a minimum, the test objectives; test approach and rationale; test conditions; test-specimen configuration; support-structure configuration; data acquisition and instrumentation requirements; and data control, storage, and retrieval provisions.

3.2 Test Condition

The combinations, rates, levels, sequence, and duration of environments and loadings which will achieve test objectives shall be applied.

3.3 Test Specimen

The size, configuration, and level of assembly of the test specimen shall be based on the type of test to be performed, the test objective, and the required accuracy of the results. Materials for the specimen shall have the structural characteristics necessary to meet the test objectives and shall duplicate as nearly as possible the materials to be used in the flight hardware. The design of the test specimen shall account for the following:

- Dimensional variations.
- Misalignments.
- Residual stresses.
- Rigging, preload, and periodic maintenance requirements.
- Location of loadings and method of applying them.
- Deployable elements.
- Location of equipment mass and center of gravity.

3.4 Support Structure

Support structure shall not cause behavior of the test specimen that will result in erroneous appraisal of the test-specimen capability. The design of the support structure shall account for the following:

- Deflection of test specimen.
- Clearances for operating units.
- Stiffness characteristics of support-structure/test-specimen interface.
- Thermal properties of support-structure/test-specimen interface.

- Distribution of stiffness, mass, structural-damping, and heat-transfer characteristics.

3.5 Data and Instrumentation

When recorded data are required to evaluate test-specimen performance, they shall be defined on the basis of the test objectives. Instrumentation to obtain the required data shall be based on the following:

- Type of data required.
- Area of interest on the specimen.
- Range of parameters to be measured.
- Accuracy of measurements.
- Frequency of measurements.
- Form of recorded data.
- Posttest data requirement.

3.6 Test Report

Test results shall be documented in a convenient form. The documentation shall contain the original data, a summary of the test results, and enough details of the test procedure to allow the test to be readily duplicated.

4. RECOMMENDED PRACTICES

4.1 Test Plan

During formulation of a design concept, available data and analytical methods should be reviewed for their applicability and accuracy. Manufacturing methods and inspection techniques should be reviewed for their ability to produce flightworthy structure repeatedly. This review will aid in determining which design-development tests are required and in establishing a test plan. The tests should be scheduled for completion early enough to allow adequate time for design changes or changes in manufacturing processes.

The comprehensive design-development test plan should contain a concise definition of the entire design-development test program. It is generally prepared in the contractor's format and should contain, as a minimum, a short summary of each test and a test schedule. On large programs, additional information such as a description of the test facility and requirements for a new facility should be included.

An individual test plan should contain a concise description of the objective and approach of each test. It is generally prepared in the contractor's format. The rationale and historical background of related tests are helpful in understanding the test and should be included for any unusual test. The test conditions, test specimen, support structure, and data requirements should be defined in detail in each individual test plan. Coordination with personnel from the test laboratory is necessary during preparation of these test plans to ensure that objectives can be met within the time and budget available.

Possible use of a design-development test as a qualification test should be evaluated early in the program, and the test plan should be reviewed to ensure compliance with qualification test criteria. Adequacy of test requirements, proper control of the test, and complete documentation of the test and its results should be confirmed by this review.

4.2 Test Condition

A test condition is a particular combination of loads and environments applied to the test specimen. Mechanical, thermal, vibrational, and acoustical loadings are applied to simulate the induced environments. Definition of the natural environments completes the definition of the test condition. One or two of the most severe test conditions should be applied first; if the test results compare satisfactorily with analytical predictions, analytical methods should then be used to predict the ability of the structure to withstand all other related conditions.

In the selection of the test condition, reference should be made to testing guidelines in other NASA design criteria monographs. (See list of monographs published to date on the last page of this document.)

4.2.1 Combination of Environments and Loadings

Combinations of test loads and environments may vary from a complex combination representing a flight condition to a simple combination or single load. The test objectives should be used as a guide in selecting the combination of loads and environments, loading levels, and sequence of loading. The test should be kept as simple as possible. However, the designer or analyst must be sure that the elimination of a load or environment will not significantly influence the behavior of the specimen.

4.2.2 Static Loading Distributions

It is not always feasible or necessary to load a structure exactly as it is loaded in flight. Therefore, design-load distributions are sometimes represented by test loadings that are easier to apply and give acceptable results. Modification of design-load distributions to obtain test loadings should be made only in those regions of the test specimen which are not critical to obtaining useful data and to meeting test objectives. When pressure due to fluid inertia causes significant stresses, alters stiffness, or affects stability, the effect of this pressure should be simulated or it should be compensated for in the test. Damage should not occur to the specimen due to modification of design-load distributions.

4.2.3 Dynamic Loading Distributions

For vibration tests, the dynamic-transfer function between the vibration-input source and the interface between the specimen and fixture should be as close to 1.0 as possible for all test frequencies. See reference 14 for a representative specification for a spacecraft-vibration test and reference 15 for an example of an experimental vibration program on a full-scale Saturn space vehicle.

Sometimes structural capability is exceeded locally in attempts to reach vibration response levels at another location. If this occurs, alternate excitation methods should be employed or vibration inputs should be relocated. To ensure that the desired specimen-loading distribution is being obtained in acoustic tests, the distribution of the sound-pressure level from the noise source, the shape and size of the specimen, and the location of the instrumentation that measures the sound-pressure levels should be examined.

4.2.4 Loading Rates

Loading rates and their control during the test usually should be specified for tests requiring time-dependent loadings. These include impact/shock, thermal, mechanical, and vacuum tests. Final judgment of loading rates, including the degree of accuracy needed, should be made by appropriate tradeoff evaluations of test laboratory capability, test complexity, sensitivity of test data to loading rates, sequence of loading application, and test objectives.

4.2.5 Temperature Effects

High or low ambient temperatures, aerodynamic heating, internal sources of heat, or combinations of these may produce significant changes in strength, increases in mechanical loading, or induced stresses. The effects of temperature usually should be simulated, especially if they are time dependent; however, if they tend to be uniformly distributed and the thermally induced stresses are small in relation to allowable stresses, these effects may be compensated for by application of the proper level of mechanical loading. Higher strength at cryogenic temperature or lower strength at elevated temperature may sometimes be compensated for in tests conducted at room temperature by selecting the proper mechanical loading based on material properties. However, a decision to test at other than the design environment must be approached with caution. For example, the flaw-growth sensitivity of most structural materials is a function of the temperature of the material and in some cases is strongly affected by the chemical activity of the contained fluid. A planned monograph on the subject of fracture control in metallic pressure vessels may be referred to for further information.

Pressure changes within a closed container from the pressure at filling temperature to the pressure at an elevated temperature may be compensated for by increasing the pressure rather than by changing the temperature, where the change in temperature is both uniform and gradual. Thermal stresses induced by a constant temperature throughout the test specimen may, depending on the complexity of the structure, be compensated for by applying the proper mechanical loading level. However, compensation for significant temperature gradients should not be attempted, but the gradients should be simulated using the proper heating system.

4.3 Test Specimen

The test specimen should be designed with careful attention to test objectives and to eliminating spurious inputs to test results. In specimen design and test planning, emphasis should be placed on obtaining data that accurately measure the capability, characteristics, or behavior of structure under known test conditions. Experimental stress-analysis techniques may employ plastic models for the determination of critical stresses and/or buckling strengths (ref. 8). Models may also be used for dynamic investigations. Specific test objectives and program requirements should determine the number of test specimens. If the test results are to be statistically interpreted, the preferred number of specimens should be based on the required confidence level.

Materials selected for the test specimen should be the same as materials used in flight hardware and in the qualification test article. However, when analyses indicate that substitution of a different material or alloy will not alter test results, substitution may be permitted.

Dimensional variations should be maintained within the tolerance ranges expected for the flight hardware. When sensitivity to dimensional variations is being evaluated by the test, control of tolerances should be maximized in the test specimen and provision made for accurate measurement of dimensional variations.

Misalignments inherent in the flight hardware should be duplicated in the test specimen. A test specimen with extreme sensitivity to misalignments should be fabricated with the tooling to be used in fabrication of the production article, if the tooling is available.

Residual stresses not eliminated in the flight hardware should, as a minimum, be estimated and their effect on test results evaluated. These stresses should be realistically represented in the test specimen if their effects are expected to alter test results significantly.

When *rigging, preload*, and *periodic maintenance requirements* are defined by tests, it is desirable to perform the tests on the first vehicle built that represents flight hardware. If an earlier test specimen must be built, it should duplicate flight hardware as nearly as possible.

Location of loadings and *method of applying them* to the test specimen should not degrade the test specimen. However, alterations may be made at regions of the specimen that are not critical for obtaining valid data and for meeting test objectives.

Deployable elements which are part of the test specimen should satisfy the following requirements:

- Have the same installation clearance between the deployable element and the remainder of the test specimen as exists in the flight hardware.
- Have no unique characteristic that requires unrepresentative power or energy to deploy.
- Have no unrealistic motions imparted to the deployable elements during transition from controlled to free motion.

Location of equipment mass and *center of gravity* in the specimen should simulate flight hardware locations when test results depend on mass distribution. Accurate simulation of mass and center of gravity can be attained by using ballast or dummy equipment if it does not degrade the test results.

4.4 Support Structure

The support-structure design should account for characteristics of the test specimen and characteristics of the actual vehicle structure which is being represented by the support structure.

4.4.1 Deflection of Test Specimen

Support structure should be designed to permit deflections of the test specimen without altering the test specimen loadings. Analysis to determine expected test specimen deflections should consider the contributions to total deflection of the following:

- Change in physical and mechanical properties of materials due to change in temperature.
- Thermal gradients.
- Yielding or buckling of the test specimen.
- Amplification of dynamic responses.
- Inelastic motion of joints.
- Differential pressures.

4.4.2 Clearances for Operating Units

Clearances between support structure and the test specimen should allow unimpeded operation of structural units and deployable elements. Allowances should be made for rigid-body motion paths, effects of linear and nonlinear deflections of the operating unit including dynamic response during deployment, and effects of basic test-specimen and support-structure deflections on the deflections and clearances of the operating unit. Allowances should also be made for deflections in a direction normal to primary deflections and for the possibility of rotational and lateral motions, even though none may be expected for normal operation.

4.4.3 Stiffness Characteristics of Support-Structure/Test-Specimen Interface

Support structure should be designed to provide realistic interface stiffness characteristics for the test specimen. Elastic and inelastic characteristics of the actual vehicle structure should be simulated by the support structure. In many cases, simulation can only be accomplished by using support structure which is identical to expected flight hardware. Representative translational and rotational deformations, including time-dependent variation of these deformations, should be part of the simulation of the support-structure stiffness.

4.4.4 Thermal Properties of Support-Structure/Test-Specimen Interface

For tests in which development of precise thermal gradients, thermal deformations, or thermal stresses is important, linear and nonlinear thermal properties of the support structure should simulate as accurately as possible the thermal properties of the flight hardware that are being represented by the support structure. To simulate these properties accurately, the support structure may have to be identical to the flight hardware. Heat transfer and mechanical characteristics of splices or conduction paths between the support structure and the test specimen should be representative of flight hardware design. These characteristics should be confirmed by analyses. If the support structure is fabricated from different alloys than the test specimen, rates of change in physical properties and radiation characteristics of the specimen and the support structure should not be disproportionate over the temperature range of the test.

4.4.5 Distribution of Stiffness, Mass, Structural-Damping, and Heat-Transfer Characteristics

The stiffness, mass, structural-damping, and heat-transfer characteristics at and adjacent to the interface between the test specimen and the support structure should simulate or be identical to those expected in the flight hardware near the test specimen, as appropriate to test objectives.

For dynamic tests, the stiffness, mass, and structural-damping distributions should be simulated. In a dynamic test where the support structure represents a very rigid test-specimen boundary, a quantitative evaluation should be made to ensure that the lowest natural frequency of the support structure is appreciably higher than the test frequencies. For static tests which confirm or establish influence coefficients, stiffness distribution, at the least, should be simulated. In functional tests, the stiffness, mass, and structural-damping distributions should be simulated, as required. In simulating stiffness, mass, and structural-damping distributions, analyses should be made to confirm that support-structure resonant frequencies will not couple with test-specimen frequencies to form unwanted coupled modes. Effects of temperature on stiffness and structural damping should be accounted for.

If the heat-transfer characteristics are significant parameters in the test, the support structure should be designed to avoid areas of heat storage and thermal conductivity and emissivity, and areas where radiation properties are unrepresentative of actual structure. The adequacy of the heat-transfer characteristics for the test should be confirmed by analyses. Effects of closures, webs, joints, and other elements of the support structure on convective, radiative, and conductive heat transfer should be included in these analyses.

4.5 Data and Instrumentation

The designer or analyst should specify the data and instrumentation requirements for a quantitative and qualitative description of the test-specimen behavior. These requirements should reflect the experience of the test engineer and the instrumentation specialists and the capability of the test laboratory. The test-laboratory engineer should confirm the capability of the intended instrumentation to meet specified data requirements.

Instrumentation should be specified to describe the relevant parameters of specimen behavior directly. In addition to data necessary to fulfill test objectives, complementary data often should be specified to support interpretation of unexpected test results. Also, data which are not directly necessary to meet test objectives should sometimes be specified for a better understanding of specimen behavior when test results are being correlated or compared with independent test data.

4.5.1 Selection of Data and Instrumentation

Selection of data to be recorded and *requirements for instrumentation* should permit valid engineering evaluation of the test-specimen behavior. Parameters which should be considered for data collection include strain, deflection, load, acceleration, temperature, pressure, position, time, and condition of the specimen. When more than one parameter can be chosen to achieve test objectives, a parameter which can be measured directly should be selected. For example, acceleration should be obtained directly from an accelerometer rather than indirectly by differentiating distance-time measurements. Where direct measurements of a parameter are not practical or could affect the specimen behavior, indirect-reading instrumentation should be selected. In addition to data required to verify that primary test objectives are met, secondary data should be gathered to substantiate or aid in the interpretation of primary data, explain unexpected specimen behavior, or enable further extrapolation of existing test data.

Location of transducers should permit measurement of meaningful data in the area of interest on the specimen and should not alter the behavior of the test specimen. Strain gages used to measure overall or gross strain distributions should not be located in areas of structural discontinuities, but should be located in areas with minimum strain gradients. Detailed information on the use of strain gages is given in references 8 and 9.

The dynamic behavior of the test specimen should not be affected by the mass of the accelerometer. Acoustical microphones should be placed or supported so that recording of structural vibrations as noise is minimal.

When measuring temperatures of thin-gage materials, temperature sensors should be located to avoid or minimize heat-sink effects of material concentrations. Temperature sensors should be located adjacent to all types of data sensors which are not temperature compensating in order to permit data correction for temperature. If data correlation with qualification test articles or flight vehicles is desired, location of transducers on the design-development test specimen should permit identical transducers and locations on qualification test articles and flight vehicles.

The *range of parameters to be measured* should be based on test experience or should be predicted by analytical methods and increased to allow for uncertainties. Instrumentation should have the required range and response characteristics (refs. 8 and 9). Where theory and experience are inadequate, the range required of instrumentation should be conservative or a preliminary test should be made to determine sensor sensitivity. Duplicate instrumentation may be needed to obtain the desired accuracy of data for low and high values of a parameter.

Accuracy of measurement should be sufficient to satisfy test requirements for discrete-point data. When the instrumentation accuracy is marginal or when it is felt that random or unexpected specimen behavior might result in apparent inaccuracies, increased frequency of data measurement, additional instrumentation, or repeated testing should be specified. Where possible, different types of data should be obtained and compared to increase confidence in conclusions drawn from the test results.

Frequency of measurements depends primarily on the type of test and the behavior of the test specimen and should be chosen to satisfy test objectives. Frequency of data measurements should ensure measurement at critical unpredictable loading values, enhance the accuracy of data by pointing up inconsistent readings, and minimize interpolation or extrapolation to define specimen behavior. In a static test, strain and deflection data should be obtained at sufficiently frequent intervals of loading to identify effects of structural yielding and buckling and to identify questionable data. Data obtained at 20-percent intervals of loading up to and including limit load and at 10-percent intervals above limit load should be adequate. Continuous time histories should be obtained during an impact/shock test and where temperature and mechanical loadings are being programmed.

The *form of the data* should effectively transmit information about the test condition and test specimen. Input data for control of the test condition and output data which define the specimen behavior should be in a form that will minimize errors caused by data manipulations and interpretations. Data supplied to the designer or analyst should include adjustments due to calibration factors. Still photographs and motion pictures (standard and high-speed) should be used to record the condition of the specimen before, during, and after the test, as appropriate.

Posttest data should be acquired to complement data obtained during the test. Although requirements for such data may not be definable before the test, the condition of the specimen after the test may enable the analyst or designer to obtain valuable information about the specimen behavior. After nondestructive tests, for example, data on the deflection that remains after removal of the static test load should be recorded to define permanent deformation. Functional elements that are not required to operate during a test should be checked after the application of limit loads to verify that they are in working order. Nondestructive leakage tests and visual, dye-penetrant, radiographic, and ultrasonic inspections should be performed to determine damage to the test specimen, if applicable.

Where failures or gross physical changes to the specimen occur, posttest photographs should be taken and nondestructive inspections should be performed. If failure is premature, fractographs should be made and other appropriate metallurgical investigations should be performed to aid in determining cause of failure. Material-properties tests may be needed to correlate the load at failure with material properties of the specimen or to assess material degradation resulting from the test. Additional tests and studies employing techniques such as photoelastic coatings, brittle lacquer coatings, or conventional two- and three-dimensional photoelasticity may be required to understand specimen behavior (ref. 8).

4.5.2 Documentation of Test Results

In addition to a list of transducers and recording instrumentation used in the test, documentation of test results should include objectives, background information, description of the specimen and support structure, test setup, test procedures, test data, unexpected instrumentation and specimen behavior, and conclusions. Facts, not opinion, should be documented. Interpretation of data and conclusions should be a coordinated activity of the designer, analyst, and test engineer. If it is necessary to include interpretations of test results, they should be explicitly stated as interpretations.

The original recorded data, whether in the form of magnetic tapes, photographs of oscilloscope traces, or handwritten notes, should be indexed, referenced, and stored for retrieval at a later date. Most test laboratories have storage files for original test data where all of the data except for those on the magnetic tapes can be stored.

The original data on magnetic tape should be digitized and printouts made which can be stored indefinitely. Normally, magnetic tapes are not stored for long periods of time. The duration of storage depends on the importance of the test and the obsolescence of data.

APPENDIX

TYPES OF TESTS

Test	Definition and comments
Static	A test to determine strength, deflection or deformation characteristics of the structure for quasi-steady loadings. Structural behavior is intended to be passive.
Life	A test to determine structural capability when the structure is subjected to repeated or sustained loadings. Structural capability is expressed in units of time, number of loading cycles, or loading level. Mechanical, thermal, vibrational, and acoustical loadings may be used singly or in combination.
Impact/shock	A test to determine structural capability, structural characteristics, or equipment environment when the structure is subjected to an impulse or shock type of loading. Impulse or shock may be generated explosively, thermally, or mechanically. Examples are pyrotechnic shock, thermal shock, landing-gear drop tests, water-landing tests, and docking tests.
Transmissibility or modal vibration	A test to determine dynamic characteristics of the structure (mode shapes, natural frequencies, damping, and response to a force input as a function of frequency). Primary structure, equipment-support structure, and equipment or simulated equipment are normally used in this test. A low-level-force input, usually a sine wave, is applied to the structure at one or more locations and the response of the structure, as a function of the frequency of the applied force, is measured at several locations. At structural resonances, relative deflections and phase angles of many points on the structure are recorded to obtain mode shapes. After the applied force(s) is removed, logarithmic decay records are used to determine damping.

TYPES OF TESTS – Concluded

Test	Definition and comments
Acoustic	A test to determine acoustic transmissibility, structural response, or equipment environment when the structure is subjected to acoustic loading. External and internal acoustic levels and vibration response of the structure may be measured. Primary structure, equipment-support structure, and actual or simulated equipment may be used. A sonic fatigue test is considered a life test since it determines structural capability.
Environmental vibration	A test to determine structural characteristics (which may include the determination of equipment environment or performance characteristics of equipment) when the structure is subjected to vibrational loading.
Aeroelastic	A test to determine the required structural stiffness to prevent a dynamic oscillatory interaction of the aerodynamic, elastic, and inertia forces acting on structure. This test, usually performed in a wind tunnel, may be conducted on any unit of full-scale structure or on dynamically scaled models.
Thermal/vacuum	A test to determine passive thermal response or active performance characteristics when the structure is subjected to thermal loading, or to a vacuum, or to both as a simulated space environment. This test is usually more significant for equipment and other subsystems than for structure.
Functional	A test performed by operating a unit of structure to determine its active performance characteristics. Ability to perform an active function is expressed in units of time, number of operations, or ability to complete the operation satisfactorily. For example, the operation of a hatch or door to ensure that clearance is sufficient for opening, that it will properly latch itself in either the open or closed position, or that the opening or closing can be accomplished in a specified time with proper loadings applied.

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